

Final (4th) report of work progress on NASA contract W-91618  
(Raytheon STX Task 3450 - 001)

**“Coronal Magnetography of Solar Active Regions Using Coordinated  
SOHO/CDS and VLA Observations”**

covering the period 6 August 1998 — 5 August 1999

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# 1 Introduction

The purpose of this project is to apply the coronal magnetographic technique of Brosius, Davila, Thomas, & White (1997; *ApJ* **488**, 488) to SOHO/CDS extreme ultraviolet (EUV) and coordinated Very Large Array (VLA) microwave observations of solar active regions in order to derive the strength and structure of the coronal magnetic field. This method exploits the dependence of the microwave emission upon the coronal magnetic field, and derives the field strength and orientation angle as functions of temperature for each spatial pixel in the field of view by minimizing the differences between the calculated and the observed brightness temperatures simultaneously for all microwave observing frequencies. The height dependence of the coronal magnetic field is obtained by combining densities, column emission measures, and filling factors (all of which can be calculated from the observed EUV emission lines) to obtain the thicknesses of the emitting volumes at various temperatures; height is obtained by summing the thicknesses of successive volumes. This project is particularly important since (i) it is widely believed that the coronal magnetic field dominates phenomena such as heating and the solar wind, and (ii) our technique currently provides the only way to measure (rather than extrapolate) the coronal magnetic field.

## 2 Achievements

In collaboration with Dr. Stephen White, I planned to obtain new SOHO/CDS and coordinated VLA microwave observations late in 1998 or early in 1999 (before the end of January), when the VLA was to have been in the most ideal configuration for this project (its new “C-short” configuration). Unfortunately, although our proposals for VLA observing time received favorable science reviews in August 1998, no observing time was allocated due to the June 1998 interruption of SOHO operations. Very little work was done on this project during the first six months of its one year term, owing largely to the extended SOHO hibernation during the summer and early fall of 1998.

After SOHO became fully operational again, we revised and resubmitted our VLA proposals, requesting observations during the next cycle (D-configuration, which is quite adequate for our purposes). The revised VLA proposals were accepted, and four observing dates were allocated. This provided 10 hours of coordinated CDS and VLA observations on each of April 12, May 9, May 13, and May 23, 1999.

In collaboration with Dr. William Thompson, I developed a CDS observing plan appropriate for obtaining the spectra needed to derive the two-dimensional distribution of an active region’s differential emission measure (DEM) required for coronal magnetography. Based upon analyses of test spectra obtained with 20 second exposures, we decided to increase the exposure time to 50 seconds. This improved the signal-to-noise of the available lines, thus increasing the likelihood that we would obtain good Gaussian profile fits to weak



but important lines like Fe XV 327 Å. It is very important to get the highest possible signal-to-noise so that we can obtain the best possible fits to the broadened line profiles in the post-recovery CDS spectra.

Samples of profile fits to test run data are shown in Figures 1 and 2. I am still in the process of determining the best possible method for routinely extracting fits to all the lines that I need. One of the problems is that the background level depends upon the selected wavelength range. If a broad enough wavelength range is selected for deriving profile fits, the background level can be so high that some of the weaker lines are effectively below the background (and not usable). Another problem is that the line profiles are so broad in the post-recovery era that closely spaced lines can appear like small peaks on a high background, when in fact they are high peaks (with blended wings) on a low background.

SOHO JOP 100 was developed, tested, approved, and implemented to obtain coordinated CDS/EIT/VLA/TRACE/SXT observations of active regions on 1999 April 12, May 9, May 13, and May 23. Collaborations were established with members of the various instrument teams, and a fair amount of effort was spent monitoring the Sun, attending planning meetings, and coordinating the observations. Analysis of all four data sets has begun, with greatest concentration on analysis of CDS data. Recent efforts have focused on learning and applying CDS software, and including it in IDL procedures that I have written to carry out coronal magnetography.

I have found that 200-pixel ( $\sim 14\text{Å}$  in NIS1) wavelength windows are appropriate for extracting broadened Gaussian line profile fit parameters for lines including Fe XIV at 334.2 Å, Fe XVI at 335.4 Å, Fe XVI at 360.8 Å, and Mg IX at 368.1 Å over the 4 arcmin by 4 arcmin CDS fields of view in JOP 100. Examples of total intensity images of NOAA region 8508 (observed on April 12) derived from line profile amplitude and width parameters (obtained with the CFIT\_BLOCK IDL procedure) are shown in Figure 3. Intensity images like these for lines formed over a wide range of temperature are essential for deriving the two-dimensional active region DEM necessary for carrying out coronal magnetography.

I have also applied the standard CDS absolute intensity calibration software to intensity images like those shown in Figure 3, and found that ratios between density-insensitive lines like Fe XVI 360.8/335.4 yield good agreement with theory. (The agreement is better when weak lines in the wings of these lines are fit separately and hence “removed.”) Interestingly, however, the resulting absolute intensities of those lines are factors  $\sim 3$  greater than I have come to expect from previous EUV (particularly SERTS) observations. This is likely a manifestation of the need to incorporate new absolute intensity calibration correction factors in the CDS software. The SERTS-97 and coordinated CDS observations indicate that correction factors  $\sim 3$  are not unreasonable. (That calibration work is currently being carried out under separate funding.) Applying an accurate CDS absolute intensity calibration is also essential to deriving reliable coronal magnetograms.



### 3 Future Direction

The (5 months of) work completed under this one-year contract period has primarily laid the groundwork upon which my subsequent SOHO Guest Investigator program (which started 1 May 1999) will be based. Although my goal was to obtain coronal magnetograms from the coordinated VLA and CDS observations, that goal could not be achieved during this contract period owing largely to the fact that the interruption in SOHO observations meant that the necessary observations were not obtained until late in the contract period. Revised CDS absolute intensity calibration factors will also need to be confirmed and incorporated into the CDS software so that reliable DEMs, necessary for coronal magnetography, can be obtained. With the lessons learned, advances made, and high quality data obtained during the past year, coronal magnetography will be successfully pursued under my new SOHO Guest Investigator program.



Extensive Temperature Coverage of Active Region Differential Emission Measures (DEM) for Coronal Heating and Coronal Magnetography Studies

Short title: Active Region DEM for Heating and Magnetography Studies

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#### SCIENCE OBJECTIVES

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This JOP provides data needed to (i) derive three-dimensional active region coronal magnetograms, and (ii) explore the nature of coronal heating.

##### (i) Active Region Coronal Magnetography

The coronal magnetographic method of Brosius et al (ApJ 488, p. 488, 1997) requires reliable measurements of plasma properties such as density, emission measure, and filling factor throughout an active region (that is, in each spatial pixel) so that one can everywhere accurately separate contributions from the different mechanisms responsible for the microwave emission. Although Brosius et al (1997) used coordinated SERTS EUV and VLA microwave observations of active regions, the same method can be applied to CDS and coordinated VLA observations as well. This method exploits the dependence of the microwave emission upon the coronal magnetic field, and derives the field strength and orientation angle as functions of temperature for each spatial pixel in the field of view by minimizing the differences between the calculated and the observed brightness temperatures simultaneously for all microwave observing frequencies. The height dependence of the coronal magnetic field is obtained by combining densities, column emission measures, and filling factors (all of which can be calculated from the observed EUV emission lines) to obtain the thicknesses of the emitting volumes at various temperatures; height is obtained by summing the thicknesses of successive volumes. Since accurate results can only be obtained if the temperature distribution of the emitting plasma is well known, we seek the widest possible temperature coverage to derive the differential emission measure (DEM) distribution. Thus we obtain (i) emission lines from CDS/NIS2 to derive the low-temperature portion of the DEM, (ii) emission lines



from CDS/NIS1 to derive the high-temperature portion of the DEM, and (iii) broad band soft X-ray filter images from Yohkoh/SXT to constrain the highest temperature contributions to the DEM. A long-term goal of this work is the routine derivation of active region coronal magnetograms.

#### (ii) Exploring the Nature of Coronal Heating

Lee et al (1997) explored the nature of coronal heating with an empirical approach involving a comparison of active region coronal temperatures with magnetic data to determine which physical quantity correlates best with observed temperature measurements on magnetic field lines. An initial application of this technique revealed that the field lines with the largest current density entering at their footpoints showed the highest temperature. This comparison was made purely with radio temperature measurements, but the technique can be improved by adding (i) measurements of the temperature distribution of the radio-emitting plasma from CDS and Yohkoh/SXT, and (ii) additional tests of the magnetic field model using field lines traced by EIT and/or TRACE images. Thus this effort combines radio, magnetic, EUV, and soft X-ray data for an active region in order to further test an empirical approach to understanding coronal heating, and to address major questions posed by the observation that the corona is not isothermal, but rather shows a mixture of temperatures along any given line of sight.

#### Observing Strategy

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##### (a) CDS

Use NIS4W to obtain 4 arcmin by 4 arcmin active region spectral data with an exposure time of 50 sec. Spatial pixel size is 4 arcsec by 6.8 arcsec. Spectra obtained over the full NIS1 and NIS2 wavebands. Entire sequence takes a little over 2 hours to complete. It is likely that the He I 584 and the O V 630 lines will saturate, but this is necessary in order to bring up the weaker Fe X - XV lines in NIS1. We would either observe the same target region multiple times (4 plus or minus 1) during the 10 hour VLA observing period to build up statistics, or else cover a wider area during the VLA observing period.

##### (b) VLA



Obtain D-configuration observations at 2, 3.5, 6, and 20 cm between 1400 and 2400 UT.

(c) Yohkoh/SXT

Obtain broad band soft X-ray observations with thin Al, AlMg, thick Al, Mg, and Be filters. This will enable widest possible temperature coverage. May need relatively long exposures with Be filter, but short compared to CDS exposure duration.

(d) EIF

Full-disk images in all four wavebands for context information and for tracing field lines. Additional 11 arcmin by 11 arcmin images of the target region in all four wavebands at midtimes of the CDS raster scans, i.e., 15, 17, 21, and 23 UT.

(e) TRACE

6.4 arcmin by 6.4 arcmin images of target active region for tracing field lines and for identifying mass motions. Use 0.5 arcsec pixels for 171, 195, and 1550 wavebands; use 1.0 arcsec pixels for 284 waveband. Separate C IV from the UV waveband. Obtain images at about 90 sec cadence.

(f) Photospheric Magnetographs

Photospheric longitudinal (from Kitt Peak Spectromagnetograph) and vector (from Advanced Stokes Polarimeter) magnetograms for extrapolating coronal magnetic fields for comparison with other data.

(g) MDI

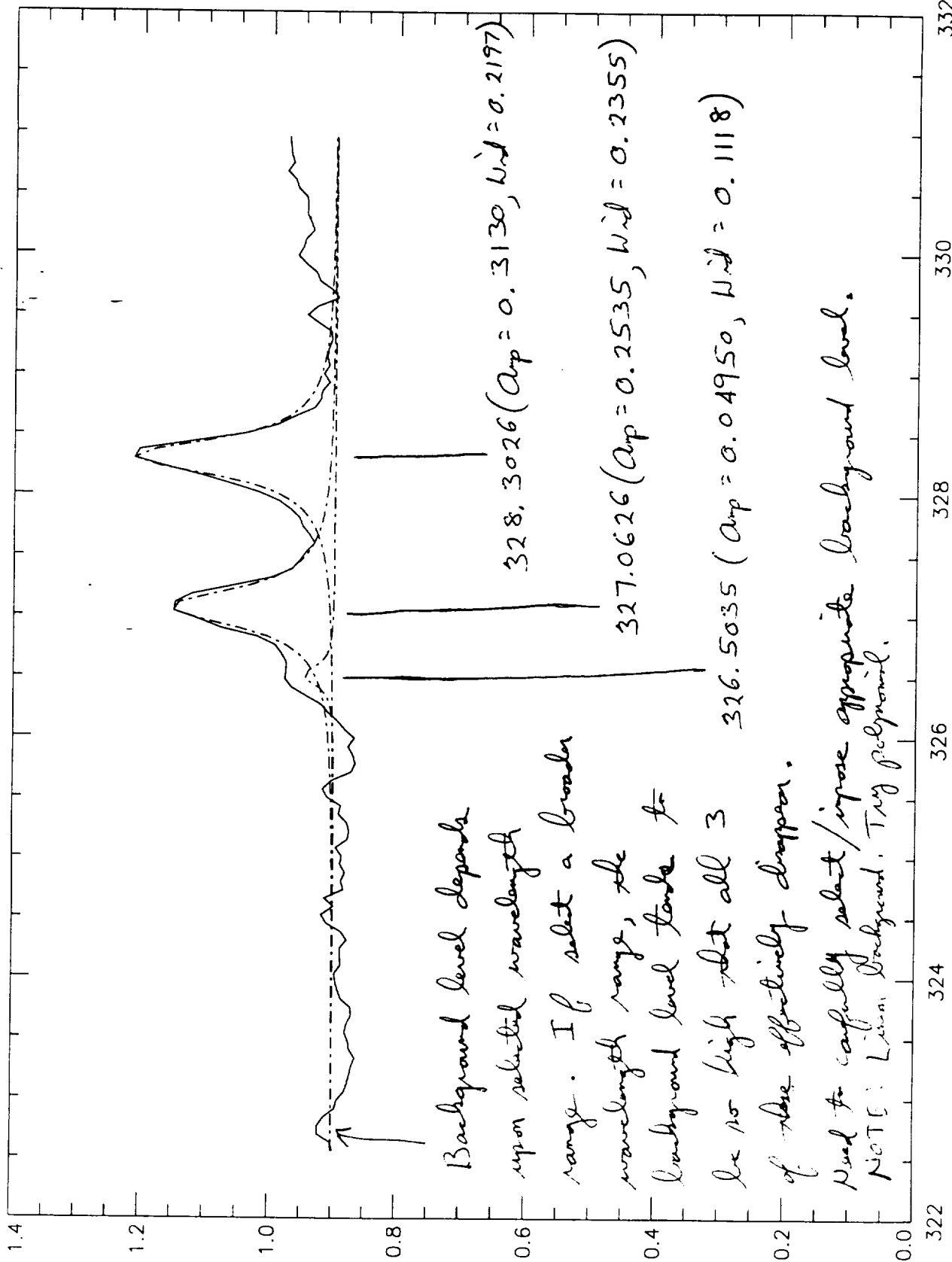
If MDI is not otherwise committed, it would be useful to obtain coordinated high-resolution magnetograms. Multiple magnetograms during the 10-hour VLA observing period would be useful to search for canceling and/or emerging flux.



# Figure 1

4/5/99

Background level depends upon selected wavelength range. If select a broader wavelength range, the background level tends to be so high that all 3 of above effectively disappear.





# Figure 2

4/6/99

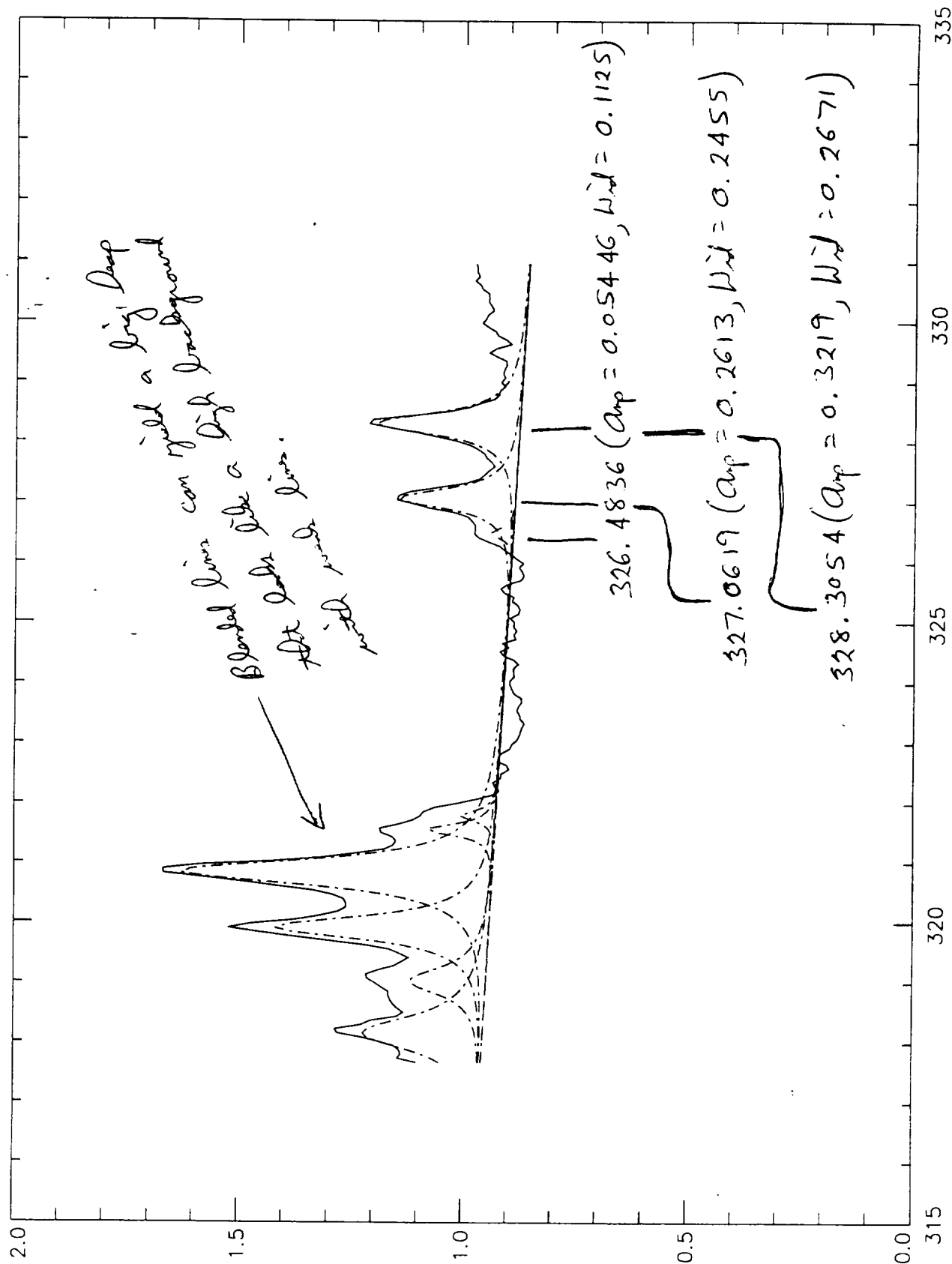
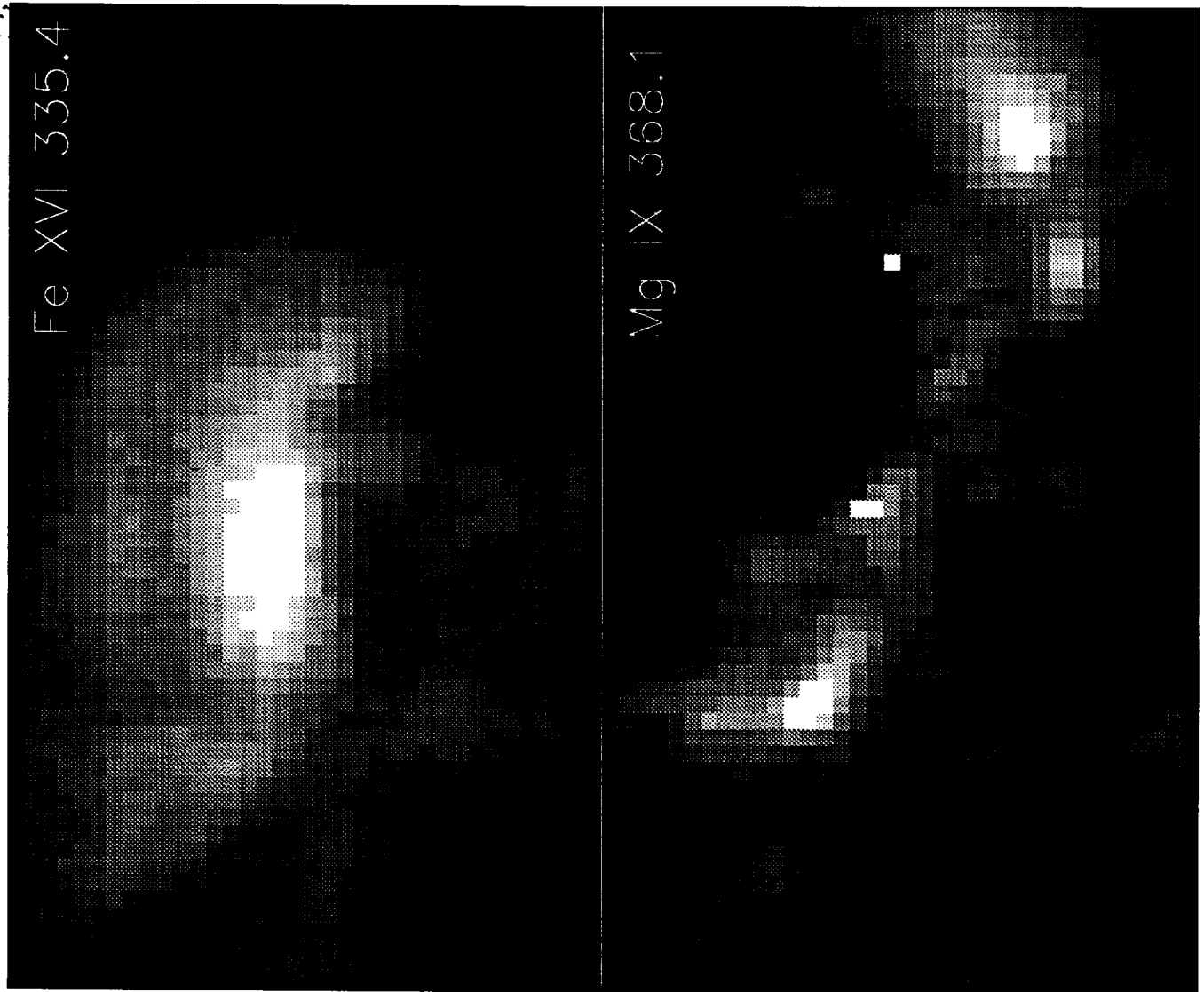




Figure 3





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16. ABSTRACT The purpose of this project is to apply the coronal magnetographic technique of Brosius, Davila, Thomas, & White (1997; ApJ 488, 488) to SOHO/CDS EUV and coordinated VLA microwave observations of solar active regions to derive the strength and structure of the coronal magnetic field. In collaboration with Dr. W.T. Thompson, a CDS observing plan was developed for obtaining spectra needed to derive active region differential emission measures (DEMs) required for coronal magnetography. In collaboration with Dr. S.M. White, VLA observations were proposed and obtained. SOHO JOP 100 was developed, tested, approved, and implemented to obtain coordinated CDS/EIT/VLA/TRACE/SXT observations of active regions on April 12, May 9, May 13, and May 23. Analysis of all four data sets began, with heaviest concentration on CDS data. It is found that 200-pixel (14 A in NIS1) wavelength windows are appropriate for extracting broadened Gaussian line profile fit parameters for lines including Fe XIV at 334.2, Fe XVI at 335.4, Fe XVI at 360.8, and Mg IX at 368.1 over the 4 arcmin by 4 arcmin CDS field of view. Extensive efforts were focused on learning and applying CDS software, and including it in new IDL procedures to carry out calculations relating to coronal magnetography. An important step is to extract Gaussian profile fits to all the lines needed to derive the DEM in each spatial pixel of any given active region. The standard CDS absolute intensity calibration software was applied to derived intensity images, revealing that ratios between density-insensitive lines like Fe XVI 360.8/335.4 yield good agreement with theory. However, the resulting absolute intensities of those lines are very high, indicating that revisions to the CDS absolute intensity calibrations remain to be included in the CDS software, an essential step to deriving reliable coronal magnetograms. With lessons learned and high quality data obtained during the past year, coronal magnetography will be successfully pursued under my new SOHO GI program.		
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